UNITED STATES DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

HANDBOOK OF CHANNEL DESIGN FOR SOIL AND WATER CONSERVATION

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In cooperation with the
Oklahoma Agricultural Experiment Station

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Introduction

The factors to consider in open-channel flow and stability, together with graphical methods for designing conservation channels, are presented in this handbook. The purpose is to furnish technicians of the Soil Conservation Service with the most recent and complete information to aid them in the design of channels to be lined with vegetation.

Complete graphical methods are presented that deal with retardance to flow offered by vegetation as a function of the depth and velocity of flow. In addition, as an aid in designing channels where the retardance may be considered constant, e.g., one with a concrete lining, a simple nomographic solution of the Manning formula has been developed. The dimensions of trapezoidal (side slopes 1:1, 1.5:1, 2:1, 2.5:1, 3:1, 4:1, 5:1, and 6:1), triangular, and parabolic channels are determined graphically. The solution for parabolic channels permits the determination of the width for any depth and the approximate side slope at each depth.

The appendix contains pertinent experimental results from which the degrees of vegetal retardance were determined and recommendations based. A list of references is included.

The method of vegetal-channel design was developed by the Stillwater Outdoor Hydraulic Laboratory of the Soil Conservation Service. The stability recommendations and capacity-design charts for completely vegetated channels are based on experimental results from this laboratory, from its former location near Spartanburg, S. C., and from the Oklahoma Agricultural Experiment Station. Information concerning Kentucky bluegrass was obtained from the Soil Conservation Experiment Station at Columbia, Mo.

[1] Early in 1946 it was determined that sufficient information was available from experiments on vegetation-lined channels (made by the Soil Conservation Service at Spartanburg, S. C., from 1937 to 1941 and at Stillwater, Okla., since 1941) to permit the development of a handbook pertaining especially to the design of channels lined with vegetation. This handbook was prepared by Vernon J. Palmer, Agricultural Engineer, Research Project OK-R-3, assisted by William P. Law, Jr., formerly of the Soil Conservation Service.

In this revised edition, the information contained in the earlier publication has been supplemented by data, graphical methods, and design charts useful in the design of vegetated channels having extremely low retardance values. This material was prepared by W.O. Ree, Hydraulic Engineer, Division of Drainage and Water Control, Soil Conservation Service--Research.

The Stillwater Outdoor Hydraulic Laboratory, Stillwater, Okla., was transferred to Agricultural Research Service of the U. S. Department of Agriculture Dec. 1, 1953.

Although developed primarily for use in the Western Gulf Region, this handbook contains values of Manning's n, general design charts, and graphical solutions that are applicable in all regions.

Open-Channel Flow

General

An open channel is defined as any conduit in which water flows with a free-water surface. Rivers, canals, and uncovered flumes are open channels. Pipes, drains, sewers, etc., act as open channels when flowing partially full. Following are definitions of a number of common terms describing flow in open channels:

Steady flow.--When the discharge or rate of flow remains constant at a cross section, the flow is described as steady. Flows in drainage channels and rivers tend to be steady except during surface-runoff periods.

Unsteady flow.--When the discharge is changing at a cross section, the flow is unsteady. Intermittent runoff into terrace outlets, meadow strips, diversion channels, and pond spillways is generally unsteady.

Uniform flow.--When the flow is steady and the mean velocity is the same at each succeeding cross section, the flow is uniform. The channel must have a constant cross section and slope. In designing ordinary vegetation-lined channels the flow is considered to be uniform at the maximum discharge.

Nonuniform flow.--When the mean velocity changes from cross section to cross section, the flow is nonuniform. Flow in the upper portions of steep channels near the entrance is nonuniform. In a channel of changing cross section the flow is nonuniform.

Notation

Q - Rate of discharge or flow in cubic meters per second.
A - Cross-sectional area of the flow in square meters.
V - Velocity of flow (mean) in meters per second.
n - Coefficient of retardance used in flow formulas. In vegetation-lined channels this coefficient contains not only the effect of lining roughness but also the effect of irregularities in bed surface, channel shape, slope, and alinement on the flow. The effect of blocking out a portion of the cross section by vegetation is also included.
R - Hydraulic radius in meters. It is the cross-sectional area A divided by the wetted perimeter.
S - Slope of energy gradient in meters per meter. In vegetation-lined channels where the flow is considered to be uniform, the bed slope in meters per meter of length may be used. The use of vertical drop and slope length in computing S is satisfactory in most vegetated channels.
d - Depth of flow in meters.
D - Depth of channel in meters after freeboard is added.

t - Width of water surface when the water is at depth d.
z - Side slope. Ratio of horizontal to vertical.
b - Bottom width of a trapezoidal channel in meters.

Character of Flow

Flow in conservation channels is turbulent. Turbulence exists when the direction and magnitude of the velocity at any point within a fluid varies irregularly with time. Considerable energy may be expended in this action. Eddying and "boiling" are visible forms of energy loss. These disturbances in the fluid are produced and maintained largely by roughness and irregularities of the bed and oscillation and sometimes severe whipping of stems and leaves of vegetation by the flow. The more violent the disturbances, the greater is the retardance to the flow and the greater are the forces acting to scour the bed.

The velocity V, as computed from Q/A or estimated from flow formulas, is the mean velocity of all components parallel to the axis of the channel. These velocity components in any vertical section range from a maximum near the surface to zero at the bed. With vegetation, the velocity distribution from surface to bed may be very nonuniform, increasingly so as the cover becomes taller, stiffer, and "bunchier."

In vegetation-lined channels, there are wide differences in velocity throughout a cross section. The water at the edges of the channel will be flowing through the vegetation at low velocities. In the deeper portions of the channel, where the vegetation has been bent over and submerged, resistance to flow will be less and velocities will be higher. The least resistance will be encountered where the flow is deepest. The velocity V, as ordinarily determined, is the mean for the entire cross section. It is apparent that channel shape affects velocity distribution. For the same mean velocity, the maximum velocity in the center of a triangular channel could be much higher than in a trapezoidal or parabolic channel. For this reason, a reduction in permissible velocities with triangular channels is desirable.

Flow in field channels lined with vegetation generally has a rough water surface. The more irregular the bed and vegetal growth and the higher the velocity, the greater is the surface roughness. The amount of aeration is also dependent upon these factors. A freeboard (vertical distance from the maximum water surface to the channel berm) allows for these conditions as well as for differences between estimated and actual discharge and capacity. Freeboards of 0.15 meter are commonly used for vegetation-lined channels.

Estimating Velocity

The design of conservation channels will be based on a mean velocity determined from the Manning formula:

$$V = \frac{1}{n} R^{2/3} \quad S^{1/2}$$

Refer to the previous section, on Notation for an explanation of the terms in this expression.

The coefficient known as Manning's n contains the effect of all the retarding influences on the flow. Kutter's n, which is used in an older, more complicated expression known as the Kutter formula and is no more accurate than Manning's for estimating the velocity, is equal to Manning's n only for a hydraulic radius of 1.0 meter. For other values of hydraulic radii, they are not identical and should not be used interchangeably. Values of Manning's n for various kinds of open channels are contained in table 1 in the Appendix.

When the channel is to be lined with vegetation, the design problem is complicated by a roughness or retardance element that changes its general position and oscillates continuously in the flow to an extent that is dependent upon the depth and velocity. To aid in designing channels of this type, a criterion has been developed for estimating n that considers the depth and velocity of the flow. A subsequent section presents this criterion together with a simple, complete, and graphical method of application.

The Manning formula will apply to uniform flow in channels. In designing ordinary vegetation-lined channels, this condition of uniform flow can be assumed to exist. For some steep channels and all channels with artificial linings (example: concrete, sheet metal, wood), careful consideration must be given to (1) inlet and outlet design and their effect on the flow in the channel, (2) changes in grade and alinement, and (3) changes in cross-sectional shape. Recourse to King's "Handbook of Hydraulics" or other qualified texts on hydraulics is recommended.

Stability of Channels

Nonvegetal Channels

With channel linings of concrete, metal, wood, etc., stability against erosion is generally not a consideration unless abrasive material is being carried in high-velocity flow. In earth channels, bare and vegetation-lined, resistance against erosion by flowing water is of principal concern. The difficulty of providing adequate protection increases with increases in both velocity and bed slope.

To aid in designing canals and irrigation and drainage channels, the Special Committee on Irrigation Hydraulics of the American Society of Civil Engineers authorized Samuel Fortier and F. C. Scobey in 1926 to prepare a paper presenting what was known about permissible velocities in bare channels of mild slope. King's "Handbook of Hydraulics" contains their conclusions. The problem is complex, depending not only upon the bed material and velocity of flow but also upon the gradation of bed material, the presence or absence of colloidal material (which acts as a cementing agent) on the bed, the age of the canal (well-seasoned canals will withstand much higher velocities than new ones), the depth of flow, and whether or not the water is clear or is transporting colloidal silts or noncolloidal material. Permissible canal velocities after aging, as recommended by Fortier and Scobey, are presented in table 2. They have been specified to apply, in a general sense, to canals with long tangents (for sinuous channels, reduce values by 25 percent) and to depths 0.92 meters or less (for greater depths an increase of velocity of 0.15 meters per second is allowable). An additional limitation not stated is that they apply only to channels of mild slope. A slope of 0.2 per cent is suggested as a reasonable upper limit.

Stability of Vegetation-Lined Channels

A common misconception has been that vegetation, bent over and completely submerged by flowing water, shingles the bed and forms a protective shield. Observations through vertical glass walls in experimental channels lined with such physically different vegetations as bermudagrass, (*Cynodon dactylon*), weeping lovegrass (*Eragrostis curvula*) and yellow bluestem (*Andropogon ischaemum*), have revealed that vegetation remains up in the flow, waving and whipping back and forth. The severity of the action is a function of the velocity, vertical distribution (as affected by slope), depth of flow, and roughness of the bed.

Vegetation protects the channel by reducing the velocity near the bed. Dense stands of long-stemmed vegetations will produce deep mats, and velocities will be low in these vegetal zones. It follows that a uniform, sod-forming vegetation having a dense, relatively deep root system will offer the greatest protection against scour. However, consideration must be given to the ability of a vegetation to reassume its normal growing position and withstand and recover from excessive deposition. Bermudagrass possesses these properties and, as known by experience, is one of the best covers to use.

With vegetal linings there are factors such as adequate stand establishment, lack of uniformity of cover, uncertainty of density and climate, rodent control, maintenance of stand, and control of deposition the evaluation of which requires experience and good judgment on the part of the technician. Since these factors are so many and varied, it is possible to present only a few general principles of vegetated-channel stability:

(a) Uniformity of cover is extremely important. The stability of a sparsely covered area is the stability of the entire channel. Weak areas should be fertilized, sodded, and treated as necessary to produce adequate cover.

(b) In construction, if practical, the topsoil should be preserved and replaced, particularly over the center portion of the channel where the flow will be deepest. When the subsoil is particularly unfavorable to vegetal growth, either a layer of good topsoil or manuring and development of a favorable soil condition is necessary.

(c) Fertilization and proper soil preparation should be done on newly constructed channels to insure rapid growth.

(d) Maintenance by mowing or controlled grazing will help to assure continuance of the desired density and uniformity of cover.

(e) Timely repair of eroded areas and protection against damage by rodents cannot be stressed too highly.

(f) Control of deposition is the first consideration of the technician when designing the channel and selecting the cover. Bunchgrasses and open covers like alfalfa, kudzu, etc., offer less retardance to low-silting flows than sod covers. Keeping covers short will reduce deposition. Wide, flat trapezoidal channels will be the most difficult to maintain from the deposition standpoint. Parabolic and triangular sections are less subject to deposition. (Unless side slopes are 6:1 or flatter, triangular sections are generally not recommended because of the undesirable velocity distribution.)

(g) If possible, keep water diverted from the channel until vegetation is well established.

To serve in designing earth channels to be lined with vegetation, permissible velocities have been determined experimentally for many different covers. Prime factors determining permissible velocities are: (a) Physical nature of vegetation (type and distribution of root growth and top growth and physical condition), (b) erodibility of soil, (c) uniformity of cover, and (d) bed slope.

Permissible velocities for bunchgrasses and other nonuniform covers are lower than where sod-forming covers are used, because (a) areas bare of vegetation exist, (b) bunchgrasses generally produce the effect of very rough beds that seriously disturb the smoothness of flow, and (c) bunchgrasses lack a dense, uniform root system.

Flow disturbances grow in severity with increase in bed slope. The ability of vegetation to provide adequate protection decreases with increase in slope.

Permissible velocities to use in design are contained in table 3. Many have been determined by experiment, others by reasonable extension and interpolation.

Design of Bare and other Nonvegetal Channels

The application of the Manning formula to hard-surfaced channels of concrete, sheet metal, wood, etc., and to earth channels free of bottom vegetation is straightforward. For the former, n can usually be assumed as constant for a given type of lining irrespective of the slope and shape of channel and depth of flow. For earth channels with bank vegetation, the selection of n for the smaller channels must be based on the width of the water surface, since some bank vegetation partially submerged has a relatively greater retarding effect in narrow channels. Table 1 contains values of Manning's n for common hard-surfaced linings and various conditions of earth channels.

A nomographic solution of the Manning formula, figure 1, and the channel-dimension diagrams for trapezoidal, triangular, and parabolic-shaped channels, figures 2 to 12 in the Appendix, permit rapid solution of all ordinary channel problems where uniform flow is involved. The following examples illustrate the solution of several types of problems:

Example 1

Given: Q = 1.416 cubic meters per second
S = 0.2 meters per kilometer

Find: The bottom width, depth of flow, and mean velocity of a drainage channel with 1.5:1 side slopes. Channel to be maintained regularly and kept free of excessive vegetal growth. Estimate n to be 0.04.

Solution: Requires one or more trial solutions. The steps are: (1) Select a velocity, (2) compute the area required from Q/V, (3) determine the required R from the nomograph (fig.1), and (4) determine the bottom width and depth from the 1:5:1 dimension diagram (fig. 3).

Item	Trial Solutions 1	2	3
V - meters per second (selected)	0.305	0.274	0.289
A - square meters (from Q/V)	4.64	5.17	4.90
R - meters (from fig. 1)	0.79	0.67	0.73
b - meters (from fig. 3)	*	4.6	2.3
D - meters (from fig. 3)		0.87	1.25

*Bottom width less than 0.6 meters. Section not practical.

Dimensions as determined by solutions 2 and 3 are practical. Choice will depend upon depth and bottom width of channel desired. If still not satisfactory, change V slightly and redetermine dimensions.

Example 2

Given: Q = 1.416 cubic meters per second

Find: The bed slope required to maintain a velocity of 0.762 meters per second in a trapezoidal channel with side slopes 3:1 and bottom width of 3.1 meters. Determine the depth of flow. Use n = 0.04.

Solution: The area required is Q/V or 1.86 square meters. Enter figure 6 (3:1 dimension diagram) with A = 1.86 and b = 3.1 and find R = 0.33 meters. In the nomograph (fig. 1) extend a line from R = 0.33 through the velocity scale at 0.762 and find the pivot point on the pivot line. Then from this point on the pivot line extend a line through n = .04 and to the slope line. The slope required is 4.0 meters per kilometer. Depth of flow (from fig. 6) will be 0.44 meters.

Example 3

Given: An existing drainage channel of these dimensions: Side slopes 3:1, bottom width 3.7 meters, depth 1.07 meters, bed slope 0.8 meters per kilometer. Channel has not been well maintained and some willows and other vegetal growth exist. Estimate n to be 0.06

Find: Present capacity allowing a 0.15 meter freeboard.

Solution: Depth of flow will be 0.92 meters. From the 3:1 dimension chart (fig. 6) R = 0.63 meters and A = 5.9 square meters. From nomograph (fig. 1) V = 0.35 meters per second. Then channel capacity = 5.9 x 0.35 = 2.06 cubic meters per second.

Design of Vegetation-Lined Channels

General

The material in this section applies to the design of terrace outlets, meadow strips, diversion channels, pond-spillway channels, and other completely vegetated channels subject to intermittent flow. The design problem is more complicated than for nonvegetal channels, since the use of a constant value for Manning's n is not usually correct where vegetal linings are used. Under the influence of velocity and depth of flow, vegetation tends to bend and oscillate continuously. The retardance to flow varies as these factors change.

It has been determined experimentally in both large and small channels, in channels of different cross-sectional shape and bed slope, and with different vegetations, that the Manning retardance coefficient n varies with VR, the product of velocity and hydraulic radius. This relationship will be referred to as the n-VR relationship. It is the basis of the vegetal-channel design method presented in this handbook.

Five general n-VR curves have been selected to apply to groups of vegetations. These curves, figure 13, were selected from a study of the experimental results presented graphically in the Appendix.

The various vegetations for which experimental n-VR relationships are available are classified in table 4 according to their degree of retardance. When a cover can be expected to be significantly shorter or much less dense than that described in the table, use the next lower degree of retardance in estimating capacity.

Above some minimum level of cover density, the tallness of the vegetation overshadows the effect of differences in density on retardance. For these conditions, only limitations as to tallness and to density conditions need be considered. Except for very sparse coverage, table 5 may be used to judge the degree of retardance.

The design of vegetation-lined channels requires that n be compatible with the value of VR. To accomplish this easily, graphical solutions of the Manning formula that apply to the five degrees of retardance, A, B, C, D, and E are presented in figures 14 to 18. These apply to flow with the vegetation completely submerged or nearly so. For shallow flow through upright vegetation with no submergence, Manning's n ceases to be related to VR. Some results of low-flow studies have been reported in the Transactions of the American Geophysical Union (April 1946).

To aid in channel design, graphical solutions of dimensions of trapezoidal (side slopes 1:1, 1.5:1, 2:1, 2.5:1, 3:1, 4:1, 5:1, and 6:1), triangular, and parabolic channels are included in figures 2 to 12.

Complete examples for using the graphical solutions are presented in subsequent sections.

The parabolic channel, offering distinct advantages for control of scour and deposition, deserves explanation. Most natural channels tend to assume this shape. The parabolic channel is defined by $d = k(t/2)^2$, where d is the depth, t the width at depth d, and k is a shape constant.

As soon as d and t have been determined for maximum flow (from fig. 11), k is automatically evaluated (a fixed point on the pivot line in fig. 12). It remains constant for the parabolic channel in question. Other combinations of depth and width for that channel must give the same value of k.

To determine other values of t and d use the nomograph in figure 12. A specific parabolic channel will have only one intersection point on the pivot line. When this is located by a straight line through the d and t for maximum flow, it serves as a pivot point that allows width to be readily determined for any other depth. In the example illustrated on the nomograph, the maximum flow was at a depth of 0.59 meters and top width of 9.8 meters. A 0.15-meter freeboard required a total depth of 0.74 meters. The top width at this depth is graphically determined to be 10.7 meters.

As an aid in judging the shape of the channel, a side-slope line is incorporated in the nomograph in figure 12. Extension of a line through a specific pivot point to this slope scale gives the approximate side slope at the depth being considered. In an initial design, a check of the side slope at maximum depth is recommended so as to assure that a steep, impractical shape is not being selected.

Selection of Channel Shape

The technician generally has some degree of freedom in the selection of channel shape. Following are some considerations that affect his decision:

(a) Equipment available for construction

If the channel is to be built with a grader, a trapezoidal (if the bottom width is greater than the minumum cut the blade will make) or triangular shape will generally be easiest to construct. A plow, bulldozer, or fresno are more suitable for construction of parabolic shapes. If a plow or ordinary grader is to be used, side slopes steeper than 4:1 cannot be constructed readily.

(b) Maintenance (by mowing)

If the vegetation in a channel is to be maintained by mowing, side slopes 3:1, 4:1, or flatter will be found desirable. A triangular channel, or relatively flat parabolic channel, will be easier to mow than a small trapezoidal channel with a bottom narrower than the length of a sickle bar.

(c) Crossing channel with equipment
Where a channel is to be crossed occasionally, with farm machinery, its side slopes should be 4:1 or flatter.

(d) Depth of excavation
Broad-bottomed trapezoidal channels require the shallowest excavation. To carry the same quantity of water, parabolic channels require a slightly deeper center excavation and triangular channels the deepest. Where depth of excavation is a limiting factor, these inherent differences between shapes should be considered.

(e) Stability
Trapezoidal channels designed and constructed with wide flat bottoms tend to silt during periods between peak discharges, thereby reducing their capacity. This silting, which occurs unevenly, results in channeling of intermediate flows and a consequent entrenching action. On the other hand, triangular channels decrease the opportunity for silting by concentrating the low flows. Since the high flows are also concentrated in the "V" of the channel, the higher velocities are more likely to produce damaging scour. The "V" of the triangular channel is the critical area. A common objection is that trickle flows of long duration seriously weaken the vegetation in the "V."

The triangular and, particularly, the trapezoidal cross sections will not maintain their shape as well as the parabolic under ordinary conditions of intermittent runoff. In fact, the trapezoidal and triangular sections tend to become parabolic in shape, due to the normal actions of channel flow, deposition, and bank erosion.

The parabolic cross section approximates the cross-sectional shape naturally assumed by many old channels. For conservation channels, this appears to be a very desirable compromise between the other two shapes, combining most of the strong points of each, with none of the undesirable characteristics of either.

Selection of Vegetation
In addition to climate and soil, which determine the type of vegetation that will grow and survive in any particular region, there are local factors that influence the selection of a vegetal lining for a channel. From a stability standpoint these, in approximate order of importance, are:

(a) Discharge to be handled
In general, the greater the discharge the better is the vegetal lining required.

(b) Bed slope
Permissible velocities decrease with increase in slope. As bed slopes increase, channeling of the flow is more likely to occur. For this reason, bunchgrasses should not be used alone on slopes steeper than 5 percent. For slopes above 5 percent,

only sod-forming covers should be used on the channel bed where the main flow occurs.

(c) Establishment

Ease of establishment and time required to develop a protective cover are extremely important considerations in selecting a vegetation. Bermudagrass and weeping lovegrass establish covers rapidly. Sometimes annuals are desirable for more immediate or earlier protection, with native grasses seeded as soon as possible. Generally, any type of temporary cover during establishment of permanent cover would be better than none at all.

(d) Suitability to farmer

If a sod cover is required, as determined by discharge and slope, but is objectionable to the farmer because of likely spreading, a combination channel might be selected. This type of channel will have, for example, bermudagrass on the bed and partially up on the sides and weeping lovegrass on the upper reaches of the side and on the berm.

(e) Deposition

Deposition may be controlled to some extent by the selection of vegetation. Low, shallow flows encounter very high retardance when flowing through sod covers like bermudagrass. A dense sod cover keeps the flow from channeling. This results in low velocities which are conducive to excessive deposition. Only when the vegetation bends and submerges will high, non-silting velocities develop.

Bunchgrasses and "open" covers like alfalfa, lespedeza, and kudzu offer less resistance to shallow flows than sod-forming covers. Velocities are higher, owing primarily to development of channeled flow. Less opportunity for deposition exists. These covers, however, offer less protection than sod covers and are limited to lesser slopes.

Illustration of Graphical Method of Design

Graphical solutions are provided in this handbook to permit rapid design of trapezoidal, triangular, and parabolic channels with five different degrees of vegetal retardance. Care has been taken to make the parabolic solution complete and as easy to use as the other two types of sections.

The degree of vegetal retardance depends largely on the tallness and density of cover, particularly the tallness. The selection of the degree of retardance for a given channel will depend mostly upon the tallness of the cover chosen. Generally, after the cover is selected, the retardance with a good uncut condition will be the one to use for capacity determination. Since a condition offering less protection exists at least during the establishment period, it is advisable to use the next lower degree of retardance when designing for stability. The procedure is to design first for stability, then, with the next higher retardance, determine the increase in depth necessary to contain the maximum discharge.

In the following example, dimensions of a trapezoidal channel with 4:1 side slopes, a triangular channel, and a parabolic channel are determined graphically for a given discharge and bed slope. Weeping lovegrass is selected as the channel lining.

<u>Given</u>: Q = 2.832 cubic meters per second
S = 3 percent
Cover - weeping lovegrass

<u>Find</u>: Dimensions of a trapezoidal channel with 4:1 side slopes, a triangular channel, and a parabolic channel that will carry this flow on a 3-percent bed slope. Uniform flow is considered.

<u>Solution</u>: Refer to table 3 and find that the permissible velocity for an average stand of weeping lovegrass on a silt-loam soil is 1.067 meters per second. Table 4 classifies weeping lovegrass under retardance A at the end of the second season. (The channels should be designed for stability, using retardance B and then provide sufficient additional depth to allow for retardance A.)

The first step is to design for stability, using retardance B. Enter the design graph for retardance B (fig. 15) with V = 1.067 and determine R = 0.30 meter. The area required is Q/V = 2.65 square meters. From dimension charts (fig. 7, 10, and 11) the following dimensions are determined:

Shape	Side slope	Bottom width b	Depth d	Width t
		meters	meters	meters
Trapezoidal	4:1	5:5	0.38	---
Triangular	7:1	0	0.61	---
Parabolic	---	---	0.46	8.5

The second step is to determine the depth of flow in the above channels under retardance A. (A cut-and-try procedure is necessary since all dimensions except depth and top width are determined.)

(a) <u>For trapezoidal channel with 4:1 side slope and b = 5.5 meters:</u> Try d = 0.49 meters. Enter figure 7 with d = 0.49 and b = 5.5 and find R = 0.38 and A = 3.6. Enter figure 14 (design chart for retardance A) with R = 0.38 and S = 3 percent and determine V = 0.68. Then capacity with d = 0.49 is AV = 3.6 x 0.68 = 2.45 cubic meters per second. Since this is significantly less than the 2.832 required, a new, slightly higher d should be investigated. Try d = 0.50. Proceeding again through figures 7 and 14 find R = 0.39, A = 3.8, and V = 0.76. Capacity with d = 0.50 is 2.89 which is adequate. Adding freeboard to this depth will give the total depth of channel.

(b) For triangular channel with 7:1 side slopes: Try d = 0.76 meters. Enter figure 10 with z = 7 and d = 0.76 and find R = 0.38 and A = 4.1. Enter figure 14 with R = 0.38 and S = 3 percent and find V = 0.68. Then capacity with d = 0.76 meters is 2.79 cubic meters per second which is adequate. Total depth of channel will be 0.76 plus freeboard.

(c) For parabolic channel with the channel shape determined by d = 0.46 meters and r = 8.5 meters: In the nomograph (fig. 12) project a line from d = 0.46 through t = 8.5 to the pivot line. The point established on this line remains fixed for this particular channel. Assuming d = 0.58 for retardance A, project (fig. 12) a straight line between this depth and the fixed point on the pivot line and determine t = 9.5 from the width scale. Then from figure 11 with d = 0.58 and t = 9.5 determine R = 0.38 and A = 3.7. Enter figure 14 (retardance A) with R = 0.38 and find V = 0.70. Then capacity at d = 0.58 equals 3.7 x 0.70 = 2.59 cubic meters per second which is too low. Try d = 0.59. From figure 12, t = 9.75. From figure 11, R = 0.39 and A = 3.9. From figure 14, V = 0.78. Then capacity = 3.04 which is satisfactory.

With parabolic channels, additional information such as the top width after a freeboard is added and widths for lesser depths is helpful. Continuing with the example: Allowing a freeboard of 0.15 meter, the following data were obtained for this parabolic channel from the nomograph, figure 12. A straight line is extended to the slope scale (through the fixed pivot point) for various combinations of d and t to arrive at the approximate side slope.

Depth d	Width t	Approximate side slope
meters	meters	
0.15	4.9	8:1
0.30	7.0	5.6:1
0.46	8.2	4.6:1
0.59 (Maximum w. s.).....	9.75	4.1:1
0.73 (with freeboard)....	10.7	3.7:1

The side slope at maximum depth (after freeboard is added) is important. If too steep, a reduction in velocity would be necessary to obtain a flatter, workable section. The above data are also useful in laying out and checking the channel in the field.

When a trial velocity does not yield a satisfactory cross section (bottom width too narrow with trapezoidal channels, or side slopes too steep with triangular and parabolic channels), a change in V of only 0.15 meters per second is recommended where the trial velocity is greater than 0.61. Dimensions will be affected greatly by this small change. Use still smaller increments of change for velocities lower than 0.61 meters per second.

SELECTED REFERENCES

(1) Cox, M. B.
1942. Tests on Vegetated Waterways. Okla. Agr. Expt. Sta. Tech. Bul. T-15, 23 pp., illus.

(2) ____________ and Palmer, V. J.
1948. Results of Tests on Vegetated Waterways. Okla. Agr. Expt. Sta. Misc. Pub. 12, 43 pp., illus.

(3) King, H. W.
1939. Handbook of Hydraulics. 3d edition, 617 pp., illus. New York and London.

(4) Palmer, V. J.
1945. A Method for Designing Vegetated Waterways. Agr. Engin. 26: 516 - 520 illus.

(5)
1946. Retardance Coefficients for Low Flow in Channels Lined with Vegetation. Amer. Geophy. Union Trans. 27: 187 - 197, illus.

(6) Ramser, C. E.
1929. Flow of Water in Drainage Channels. U. S. Dept. Agr. Tech. Bul. 129, 101 pp., illus.

(7) Ree, W. O., and Palmer, V. J.
1949. Flow of Water in Channels Protected by Vegetative Linings. U. S. Dept. Agr. Tech. Bul. 967, 115 pp., illus.

(8) Scobey, F. C.
1933. The Flow of Water in Flumes. U. S. Dept. Agr. Tech. Bul. 393, 98 pp., illus.

(9) ____________
1939. Flow of Water in Irrigation and Similar Canals. U. S. Dept. Agr. Tech. Bul. 652, 78 pp., illus.

(10) Smith, D. D.
1946. Bluegrass Terrace Outlet Channel Design. Agr. Engin. 27: 125 - 130, illus.

TABLE 1.--Values of Manning's n

Item	Manning's n
Nonvegetal Channels[1]:	
Wooden flumes--planed (no battens)	0.010 - 0.014
Wooden flumes--unplaned (no battens)	.011 - .015
Metal flumes--smooth	.011 - .015
Metal flumes--corrugated	.022 - .030
Vitrified clay tile	.012 - .017
Concrete--finished	.011 - .014
Concrete--unfinished	.015 - .020
Masonry--rubble	.017 - .030
Masonry--dry-rubble	.025 - .035
Earth channels subject to intermittent flow:	
Bare--unable to support vegetal growth or vegetal growth is not permitted by farm operations	
Straight and uniform	.017 - .025
Dredged (rough bed)	.025 - .035
Vegetal lining--use a retardance coefficient n related to the product of velocity and hydraulic radius. Use figures 14 to 18 to solve graphically the Manning formula for five degrees of vegetal retardance so that n will be compatible with VR. Use tables 4 and 5 as a guide in selecting the degree of retardance.	
Earth channels subject to continuous flow[2]:	
Canals and ditches with continuous flow or sufficiently frequent flow to keep vegetation from growing on the bed.	
A. Channels with unusually good alinement, relatively smooth beds and side slopes. Banks fairly well vegetated but no vegetation or large obstructions on the bed.	
Product of top width and depth	
Up to 10	.030 - .040
10 to 20	.020 - .030
Greater than 20	.017 - .025
B. Channels with average bed and side-slope roughness and alinement. Banks fairly well vegetated. Average maintenance.	
Product of top width and depth	
Up to 10	.045 - .050
10 to 20	.040 - .045
Greater than 20	.030 - .040
C. Channels choked with weeds and willows. Values of n as high as 0.15 may develop.	

[1]Selected from table of Horton's values of n in King's "Handbook of Hydraulics."
[2]Reference to U. S. Dept. Agr. Technical Bulletins by C. E. Ramser and F. C. Scobey (see references) is recommended.

TABLE 2.--Permissible canal velocities after aging; for channels with linings other than vegetation[1]

Original material excavated	Clear water, no detritus	Water transporting colloidal silts	Water transporting noncolloidal silts, sands, gravels, or rock fragments
	meters per sec.	meters per sec.	meters per sec.
Fine sand, noncolloidal....................	0.457	0.762	0.457
Sandy loam, noncolloidal..................	0.533	0.762	0.610
Silt loam, noncolloidal....................	0.610	0.914	0.610
Alluvial silts, noncolloidal..............	0.610	1.067	0.610
Ordinary firm loam.........................	0.762	1.067	0.686
Volcanic ash...............................	0.762	1.067	0.610
Fine gravel................................	0.762	1.524	1.143
Stiff clay, very colloidal................	1.143	1.524	0.914
Graded, loam to cobbles, noncolloidal......	1.143	1.524	1.524
Alluvial silts, colloidal.................	1.143	1.524	0.914
Graded, silt to cobbles, colloidal.........	1.219	1.676	1.524
Coarse gravel, noncolloidal................	1.219	1.829	1.981
Cobbles and shingles.......................	1.524	1.676	1.981
Shales and hardpans........................	1.829	1.829	1.524

[1]Recommended in 1926 by Special Committee on Irrigation Research, American Society of Civil Engineers.

Although not specifically stated in the original recommendations, these values apply only to channels with mild bed slopes.

TABLE 3.--Permissible velocities for channels lined with vegetation[1]
The values apply to average, uniform stands of each type of cover.

Cover	Slope range[2]	Permissible velocity	
		Erosion resistant soils	Easily eroded soil
	Percent	Meters per sec.	Meters per sec.
Bermudagrass	0-5	2.438	1.829
	5-10	2.134	1.524
	over 10	1.829	1.219
Buffalograss Kentucky bluegrass Smooth brome Blue grama	0-5	2.134	1.524
	5-10	1.829	1.219
	over 10	1.524	0.914
Grass mixture	[2]0-5	1.524	1.219
	5-10	1.219	0.914
Lespedeza sericea Weeping lovegrass Yellow bluestem Kudzu Alfalfa Crabgrass	[3]0-5	1.067	0.762
Common lespedeza[4] Sudangrass[4]	[5]0-5	1.067	0.762

[1]Use velocities exceeding 1.524 meters per second only where good covers and proper maintenance can be obtained.
[2]Do not use on slopes steeper than 10 percent except for side slopes in a combination channel.
[3]Do not use on slopes steeper than 5 percent except for side slopes in a combination channel.
[4]Annuals--used on mild slopes or as temporary protection until permanent covers are established.
[5]Use on slopes steeper than 5 percent is not recommended.

TABLE 4.--Classification of vegetal covers as to degree of retardance

Note: Covers classified have been tested in experimental channels. Covers were green and generally uniform.

Retardance	Cover	Condition
A	Weeping lovegrass....................	Excellent stand, tall, (average 76.2 centimeters)
	Yellow bluestem Ischaemum............	Do tall, (average 91.4 centimeters)
B	Kudzu................................	Very dense growth, uncut
	Bermudagrass.........................	Good stand, tall, (average 30.5 centimeters)
	Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses)....................	Good stand, unmowed
	Weeping lovegrass....................	Good stand, tall, (average 61.0 centimeters)
	Lespedeza sericea....................	Good stand, not woody, tall (average 48.3 cent.)
	Alfalfa..............................	Good stand, uncut, (average 27.9 centimeters)
	Weeping lovegrass....................	Good stand, mowed, (average 33.0 centimeters)
	Kudzu................................	Dense growth, uncut
	Blue grama...........................	Good stand, uncut, (average 33.0 centimeters)
C	Crabgrass............................	Fair stand, uncut (25.4 to 121.9 centimeters)
	Bermudagrass.........................	Good stand, mowed (average 15.2 centimeters)
	Common lespedeza.....................	Good stand, uncut (average 27.9 centimeters)
	Grass-legume mixture--summer(orchard grass, redtop, Italian ryegrass, and common lespedeza).....................	Good stand, uncut (15.2 to 20.3 centimeters)
	Centipedegrass.......................	Very dense cover (average 15.2 centimeters)
	Kentucky bluegrass...................	Good stand, headed (15.2 to 30.5 centimeters)

TABLE 4. (con.)

Retardance	Cover	Condition
D	Bermudagrass.........................	Good stand, cut to 6.4-centimeter height
	Common lespedeza.....................	Excellent stand, uncut (average 11.4 centimeters)
	Buffalograss.........................	Good stand, uncut (7.6 to 15.2 centimeters)
	Grass-legume mixture--fall, spring(Orchardgrass, redtop, Italian ryegrass, and common lespedeza).................	Good stand, uncut (10.2 to 12.7 centimeters)
	Lespedeza sericea....................	After cutting to 5.1-centimeter height. Very good stand before cutting.
E	Bermudagrass.........................	Good stand, cut to 3.8 centimeters
	Bermudagrass.........................	Burned stubble.

TABLE 5.--Guide to selection of vegetal retardance

Stand	Average length of vegetation	Degree of retardance
	Longer than 76.2 cm.	A
	27.9 to 61.0 cm.	B
Good......	15.2 to 25.4 cm.	C
	5.1 to 15.2 cm.	D
	Less than 5.1 cm.	E
	Longer than 76.2 cm.	B
	27.9 to 61.0 cm.	C
Fair......	15.2 to 25.4 cm.	D
	5.1 to 15.2 cm.	D
	Less than 5.1 cm.	E

TABLE 6.--Source of experimental results presented in figures 19 to 22

Identification number	Source[1]	Channel	Expt.	Date
1...............	a	U6	3	Fall, 1945
2...............	a	U4	1	Fall, 1945
3...............	a	U2	2	Fall, 1945
4...............	b	B2-9	2	Fall, 1939
5...............	b	B2-14B	1	Summer, 1940
		B2-10B	1	Summer, 1941
6...............	c	1D, 4D, 7B	1	Fall, 1943
7...............	a	U6	1	Fall, 1944
8...............	c	2C, 4B	1	Fall, 1943
9...............	c	1D, 2D, 4B, 7F, 10D	1	Fall, 1940
10...............	b	B2-9	1	Fall, 1938
11...............	a	U5	3	Fall, 1945
12...............	a	L1A	2	Fall, 1945
		FC3B	1	Fall, 1945
13...............	b	B2-6	1	Fall, 1938
14...............	b	B2-5	1	Fall, 1938
15...............	b	B2-16B	1	Summer, 1940
		B2-12B	1	Summer, 1941

TABLE 6. (con.)

Identification number	Source[1]	Channel	Expt.	Date
16...............	b	B1-4	1	Fall, 1939
17...............	d	--	-	Summers, 1943-44
18...............	a	U3	3	Fall, 1945
19...............	c	Results from a group of channels varying in slope from 1 to 10 percent		Fall, 1942
20...............	b	B2-15B	1	Summer, 1940
21...............	b	B2-12C	1	Spring, 1941
		B2-16C	1	Spring, 1940
		B2-16A	1	Fall, 1940
22...............	b	B2-14A	1	Fall, 1940

[1]Source	Investigator
a	Stillwater Outdoor Hydraulic Laboratory, Soil Conservation Service, Research Project OK-R-3, Stillwater, Okla.
b	Spartanburg Outdoor Hydraulic Laboratory, Soil Conservation Service, Research Project SC-R-2, Spartanburg, S.C.
c	Oklahoma A & M Agricultural Experiment Station, Stillwater, Okla.
d	Soil Conservation Experiment Station, Soil Conservation Service, Research Project, Columbia, Mo.

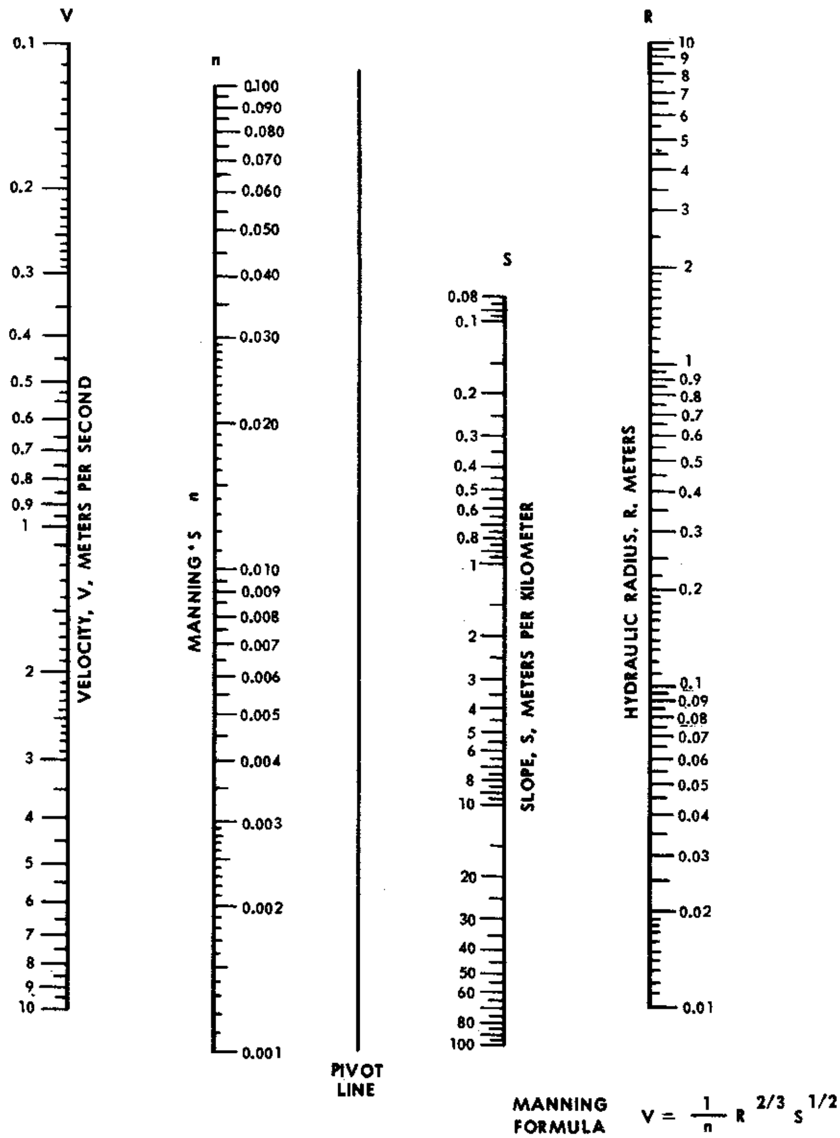


Figure 1. -- Solution of the Manning formula.

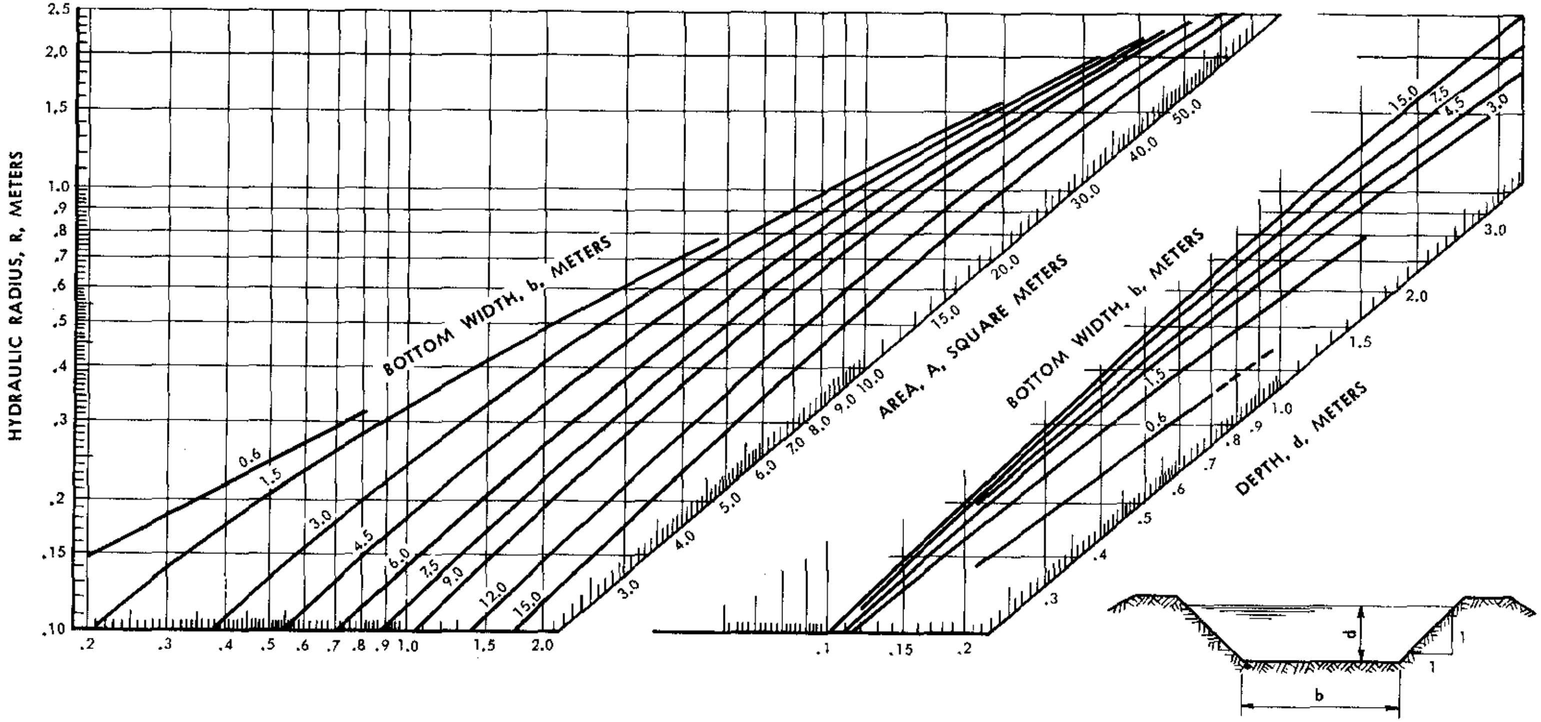


Figure 2. -- Dimensions of trapezoidal channels with 1 to 1 side slopes.

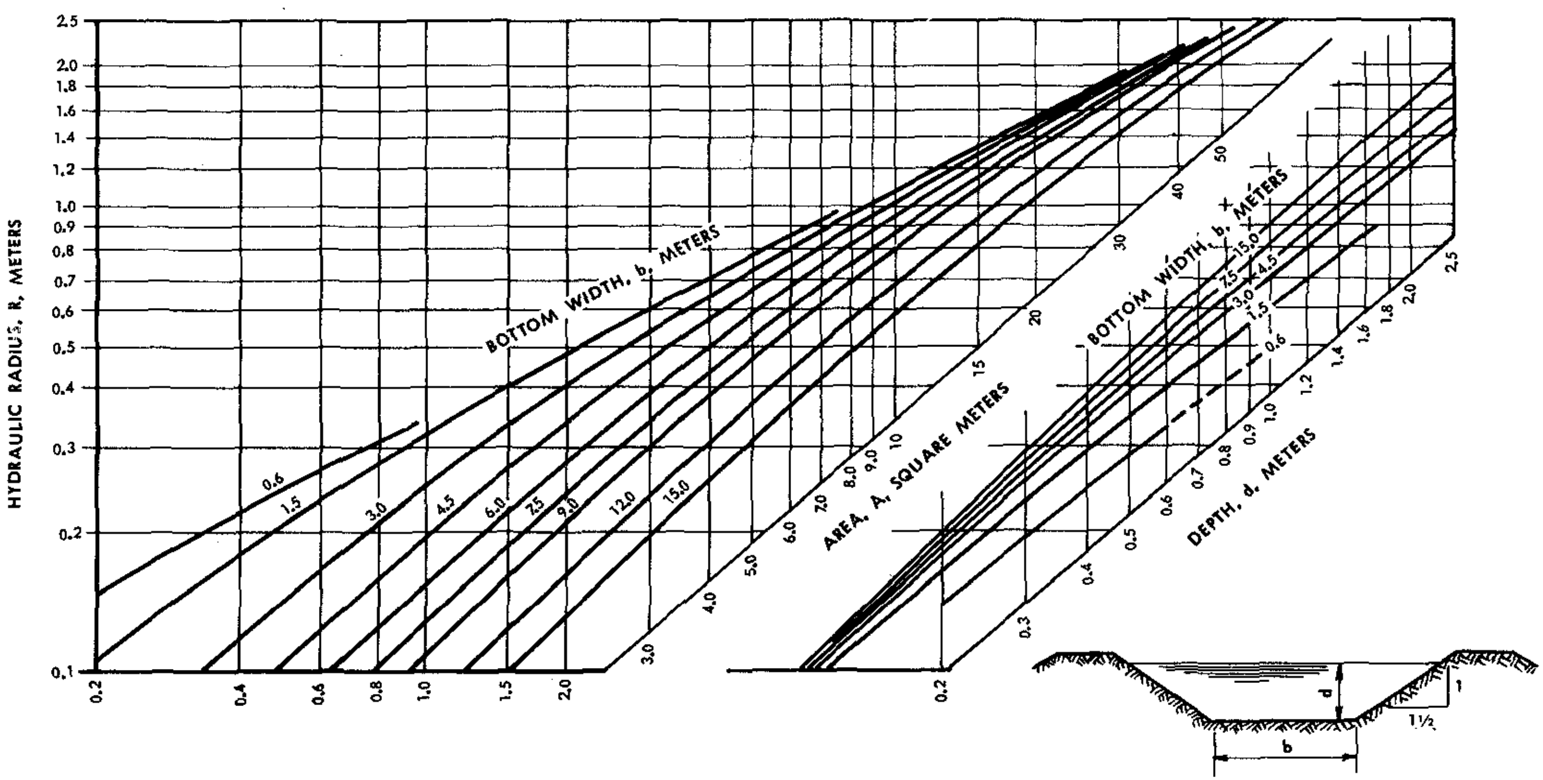


Figure 3. -- Dimensions of trapezoidal channels with 1-1/2 to 1 side slopes.

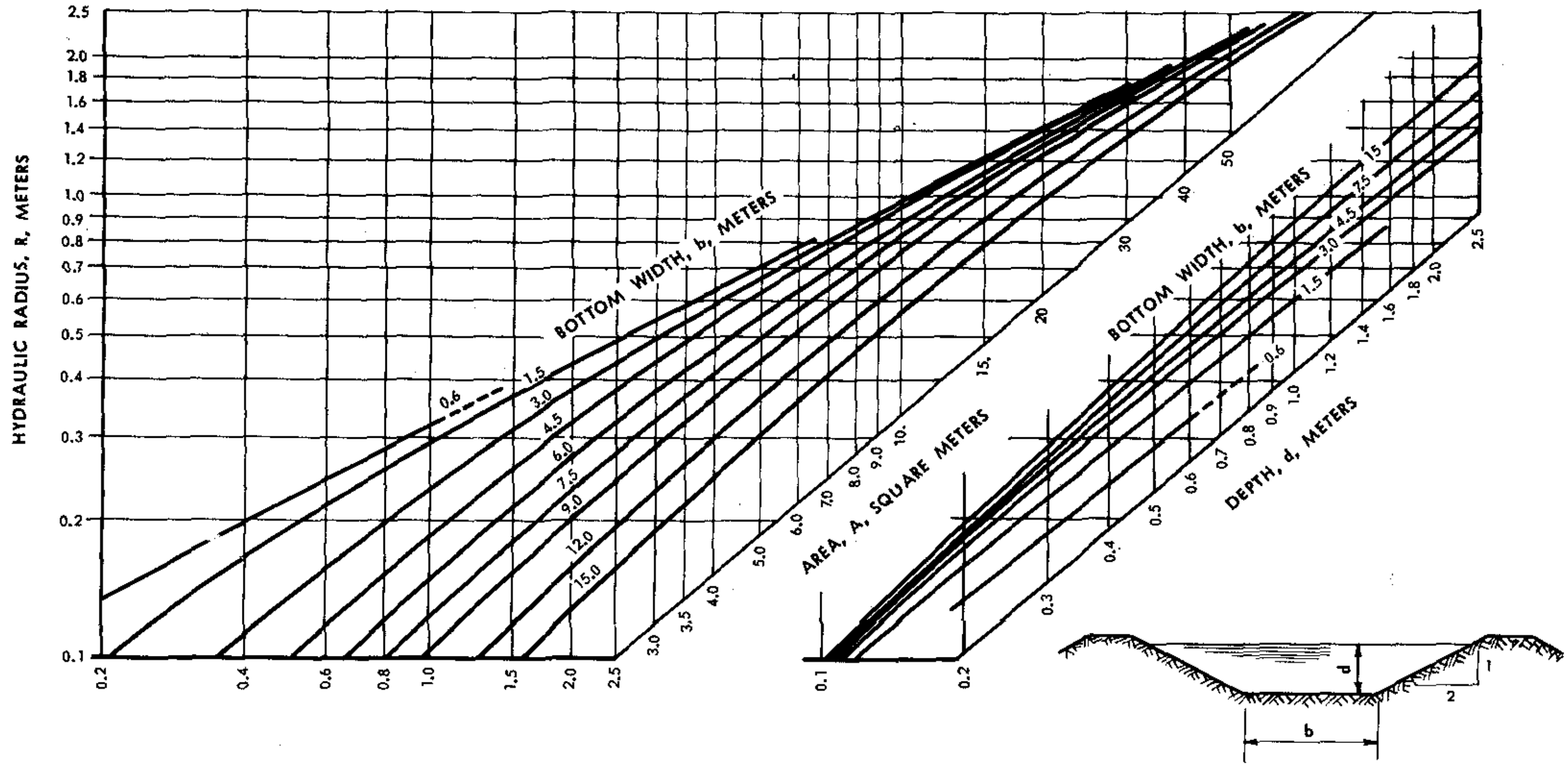


Figure 4.-- Dimensions of trapezoidal channels with 2 to 1 side slopes.

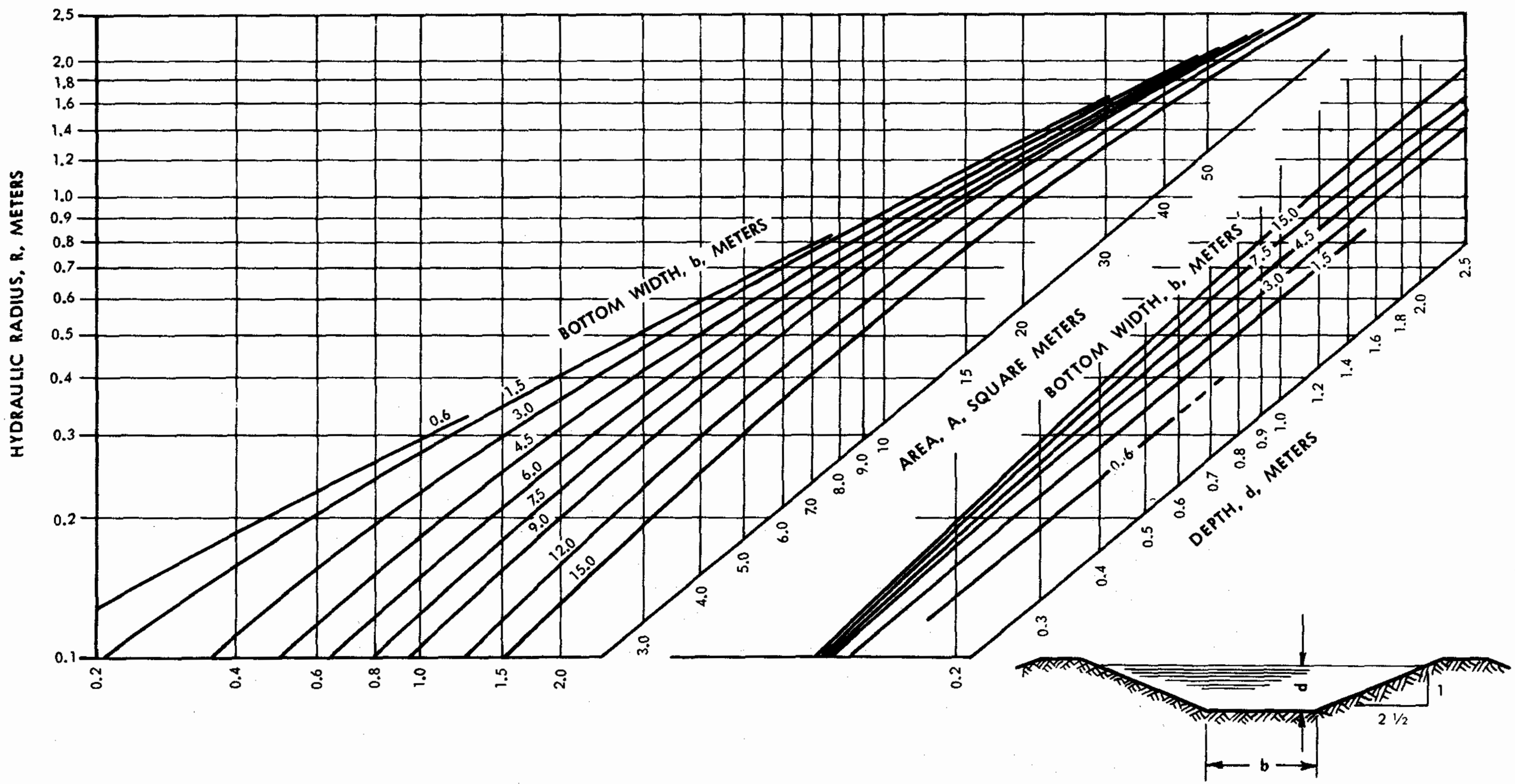


Figure 5. -- Dimensions of trapezoidal channels with 2-1/2 to 1 side slopes.

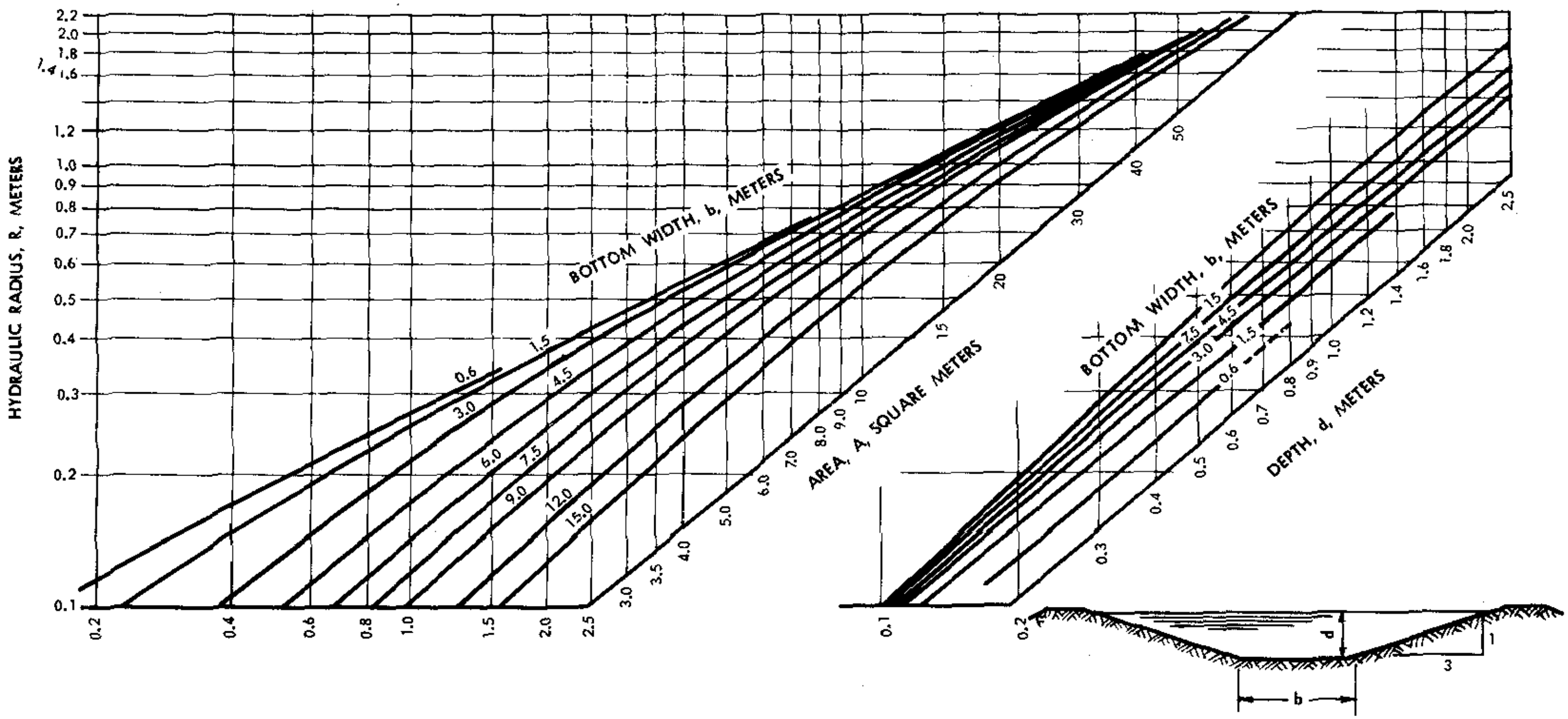


Figure 6. -- Dimensions of trapezoidal channels with 3 to 1 side slopes.

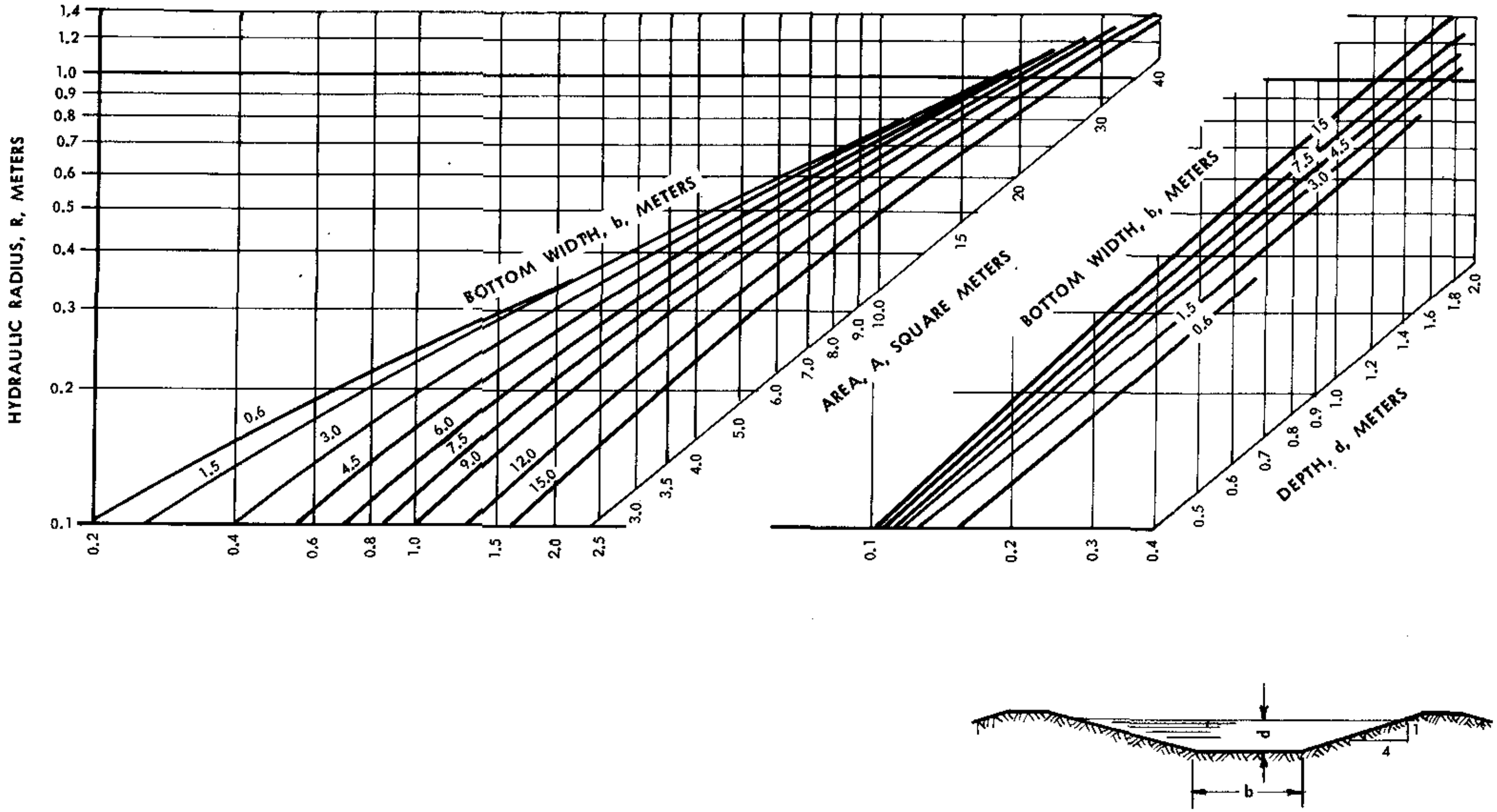


Figure 7. -- Dimensions of trapezoidal channels with 4 to 1 side slopes.

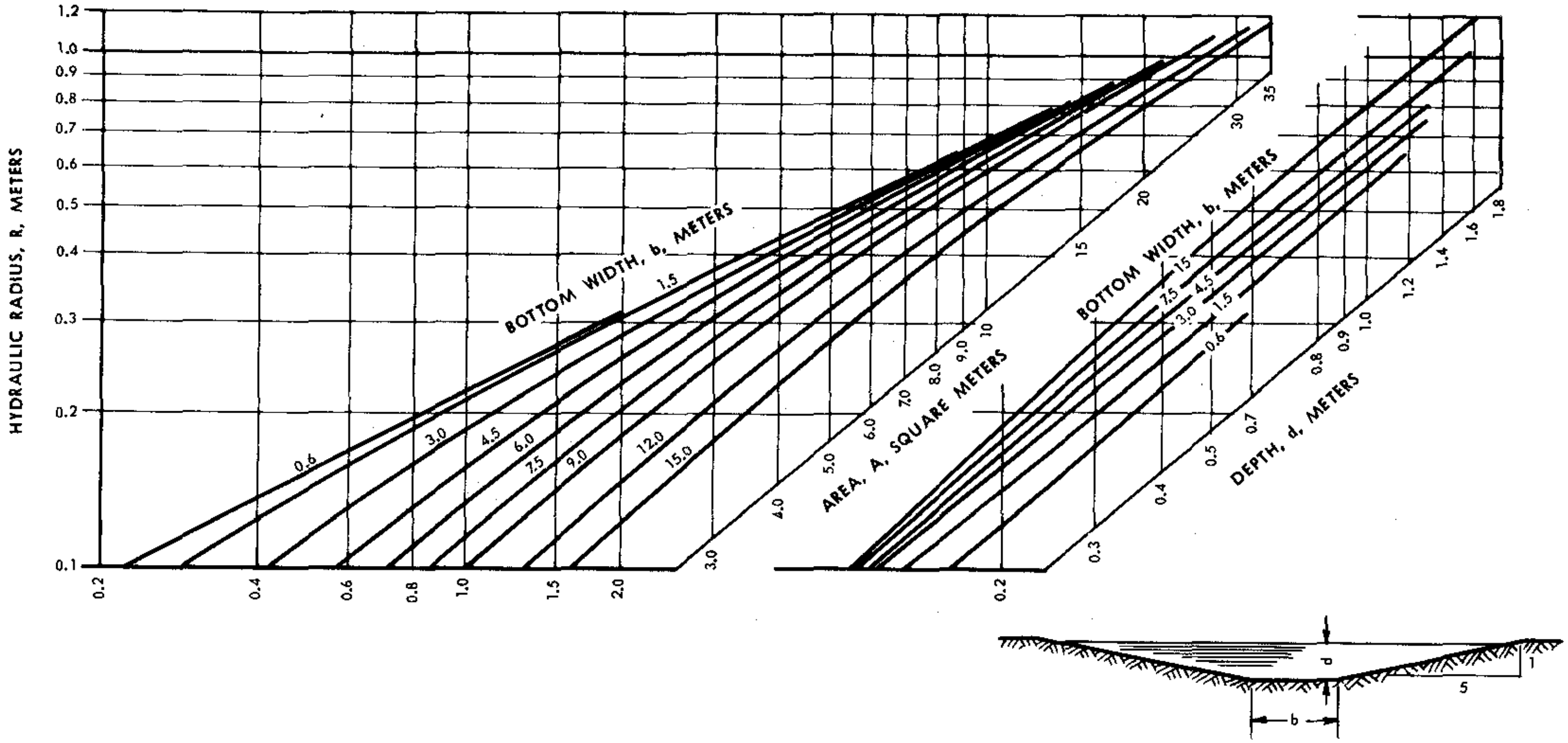


Figure 8. -- Dimensions of trapezoidal channels with 5 to 1 side slopes.

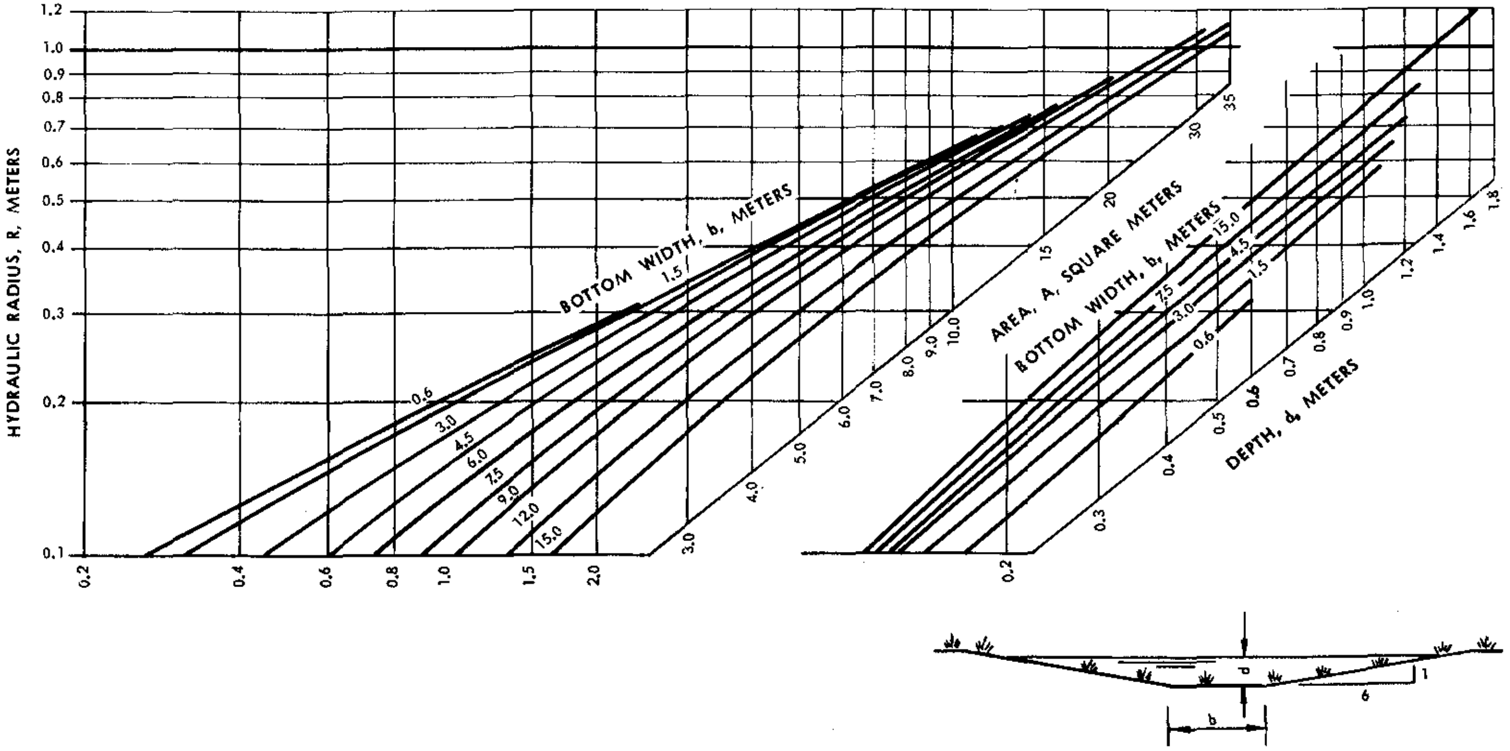


Figure 9.-- Dimensions of trapezoidal channels with 6 to 1 side slopes.

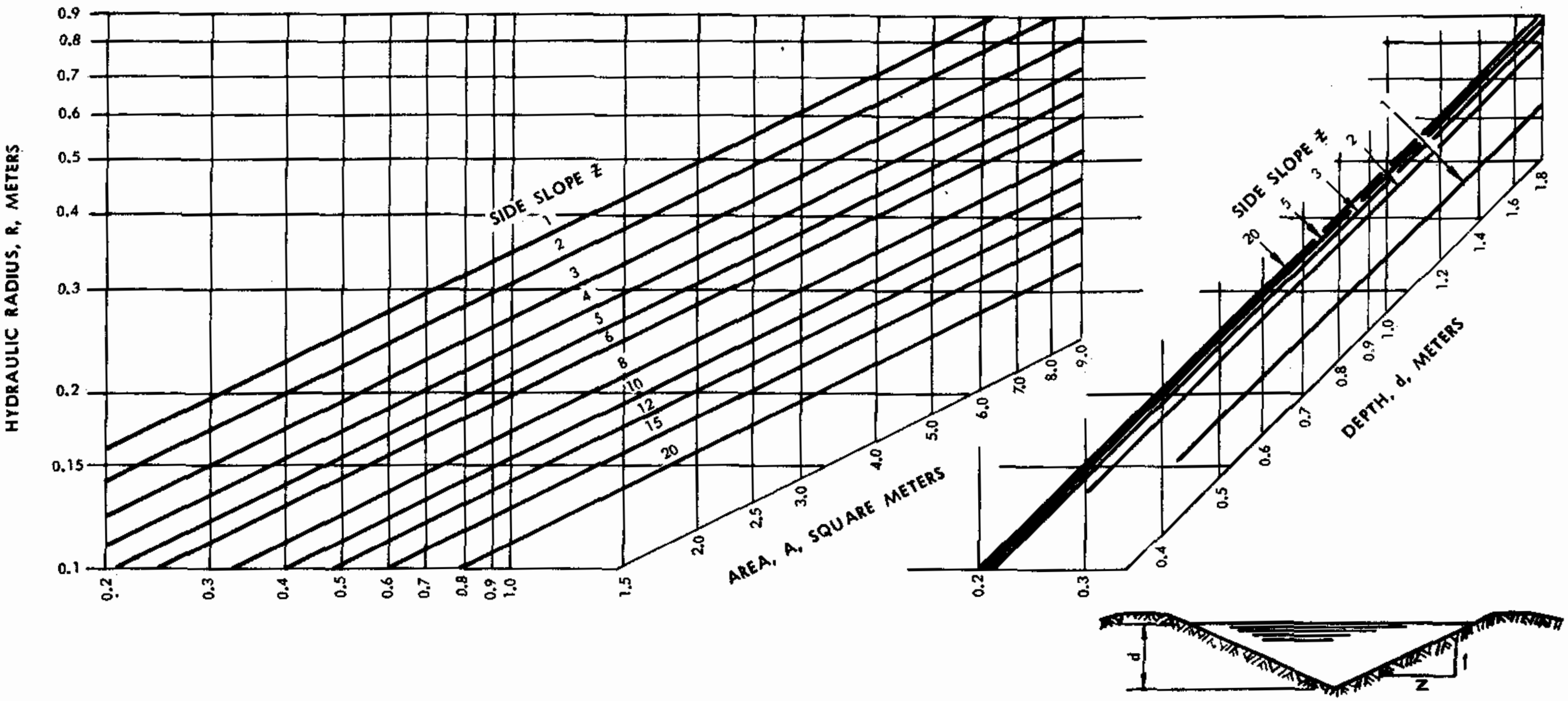


Figure 10. -- Dimensions of triangular channels.

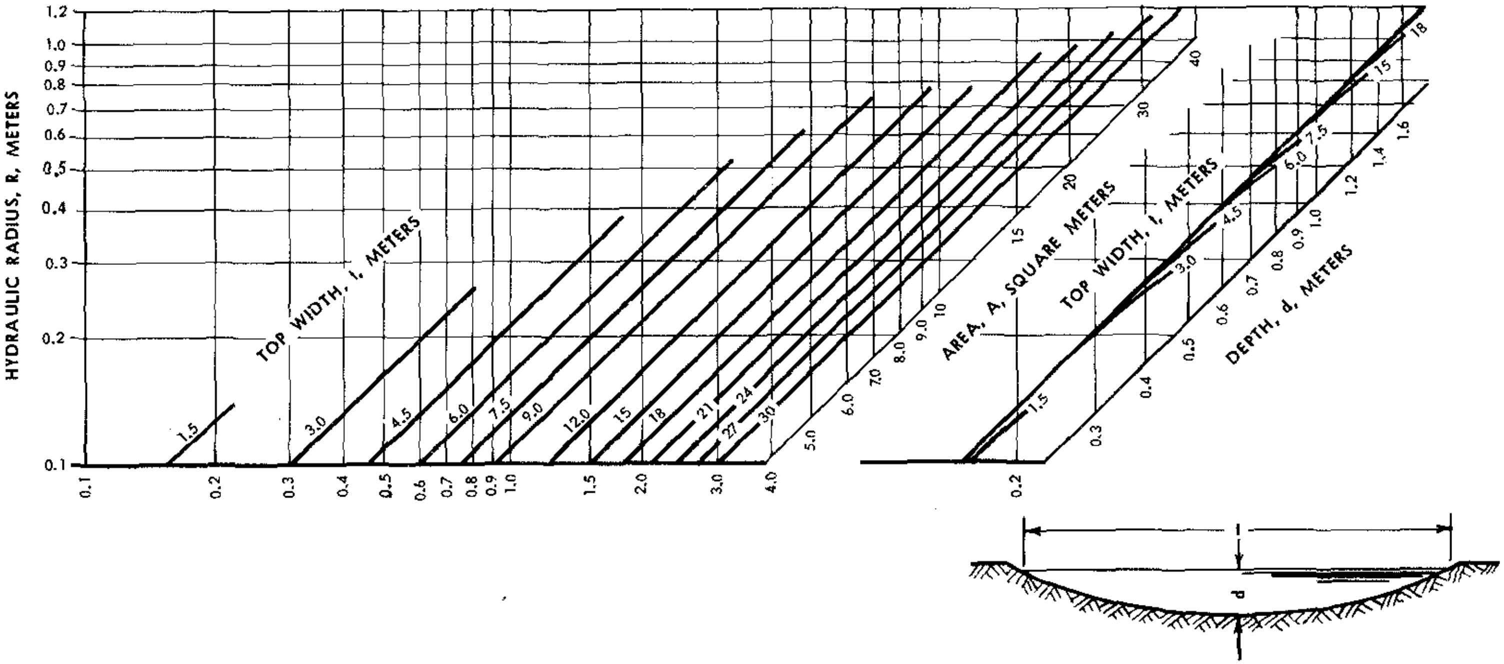
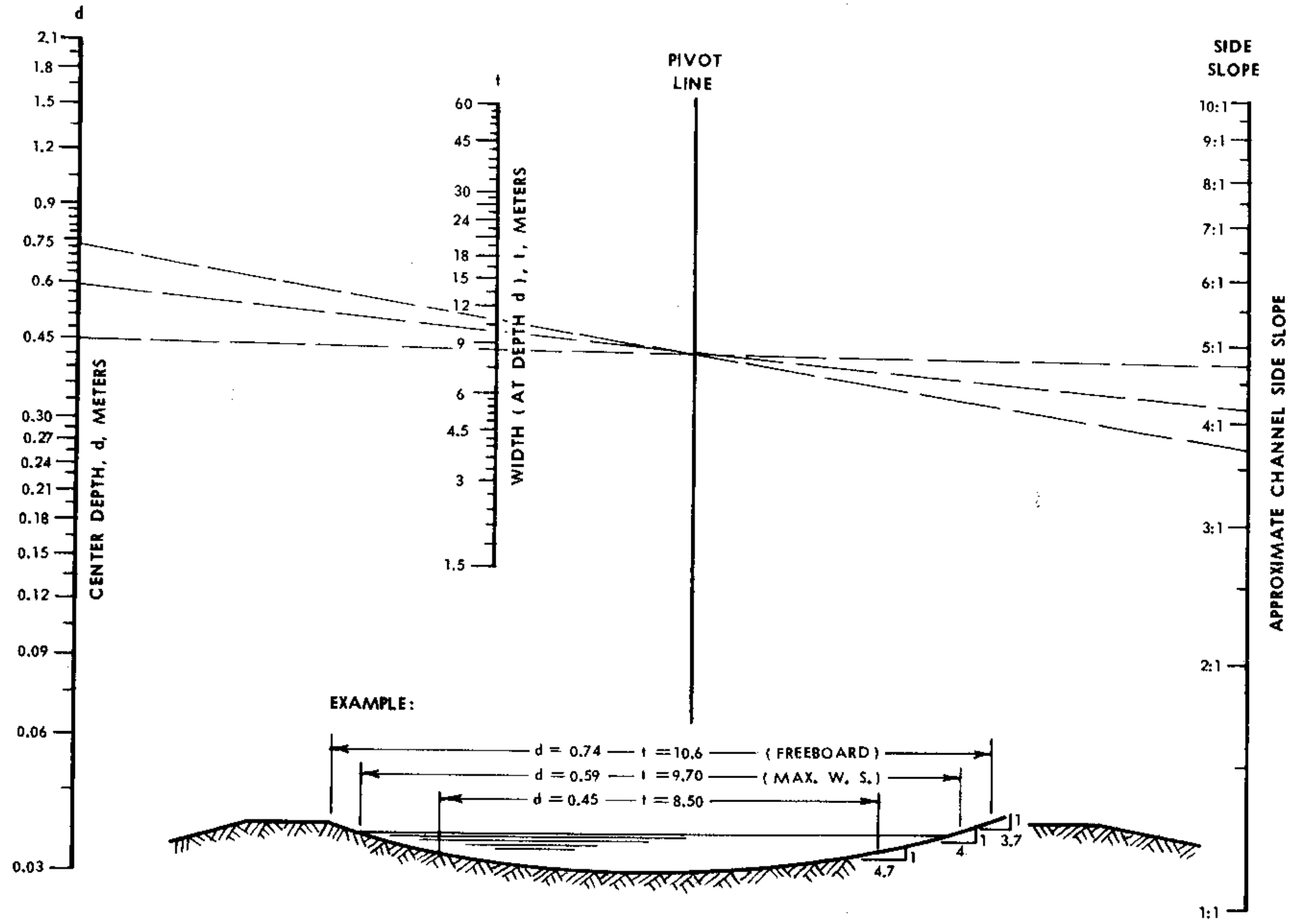


Figure 11. -- Dimensions of parabolic channels.



NOTE: THIS CHART TO BE USED TO OBTAIN OTHER DIMENSIONS AFTER t AND d FOR MAXIMUM FLOW HAVE BEEN DETERMINED (FROM FIG. 11)

Figure 12. -- Solution for dimensions of parabolic channels.

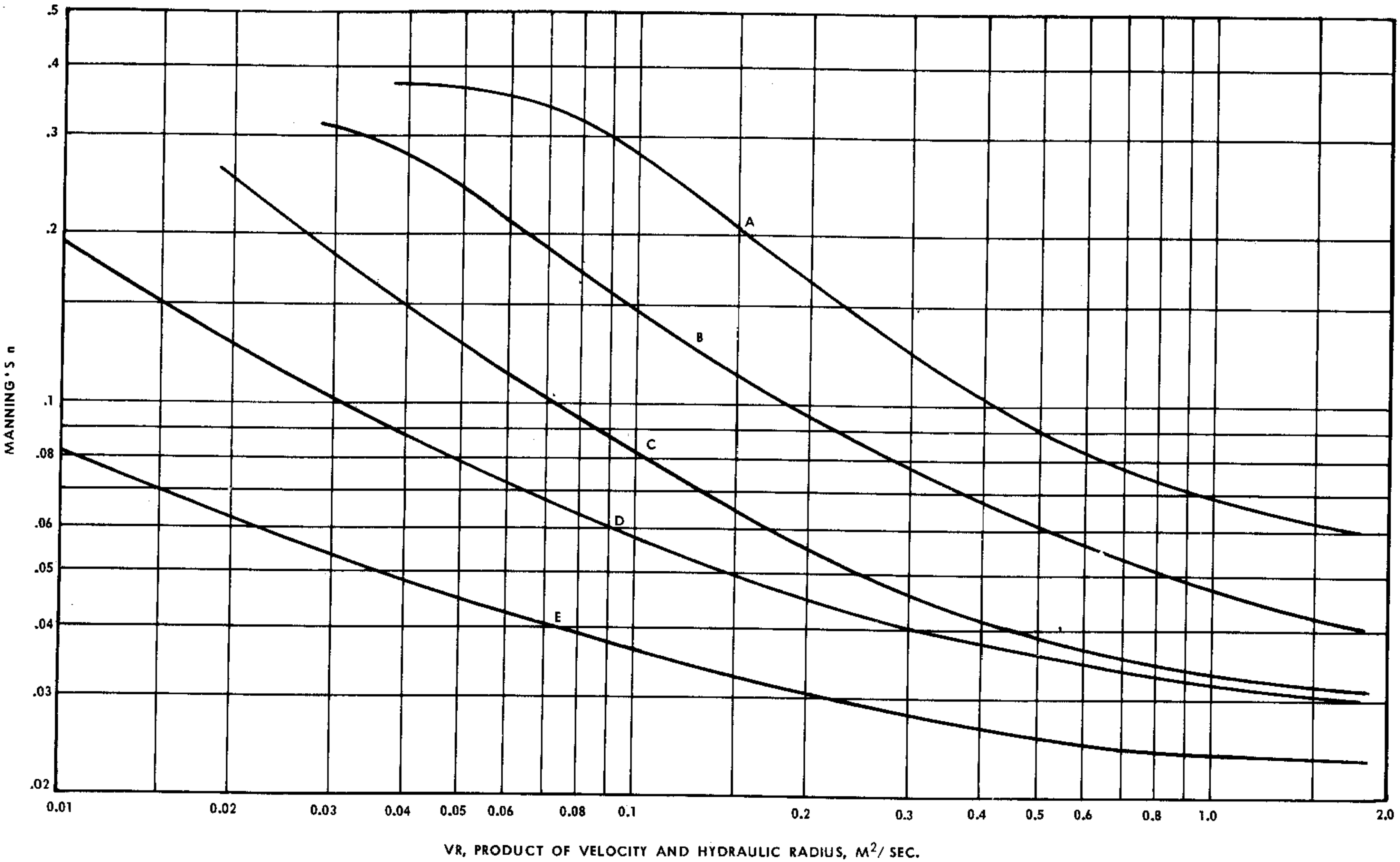


Figure 13. -- Degrees of vegetal retardance for which graphical solutions of the Manning formula have been prepared.

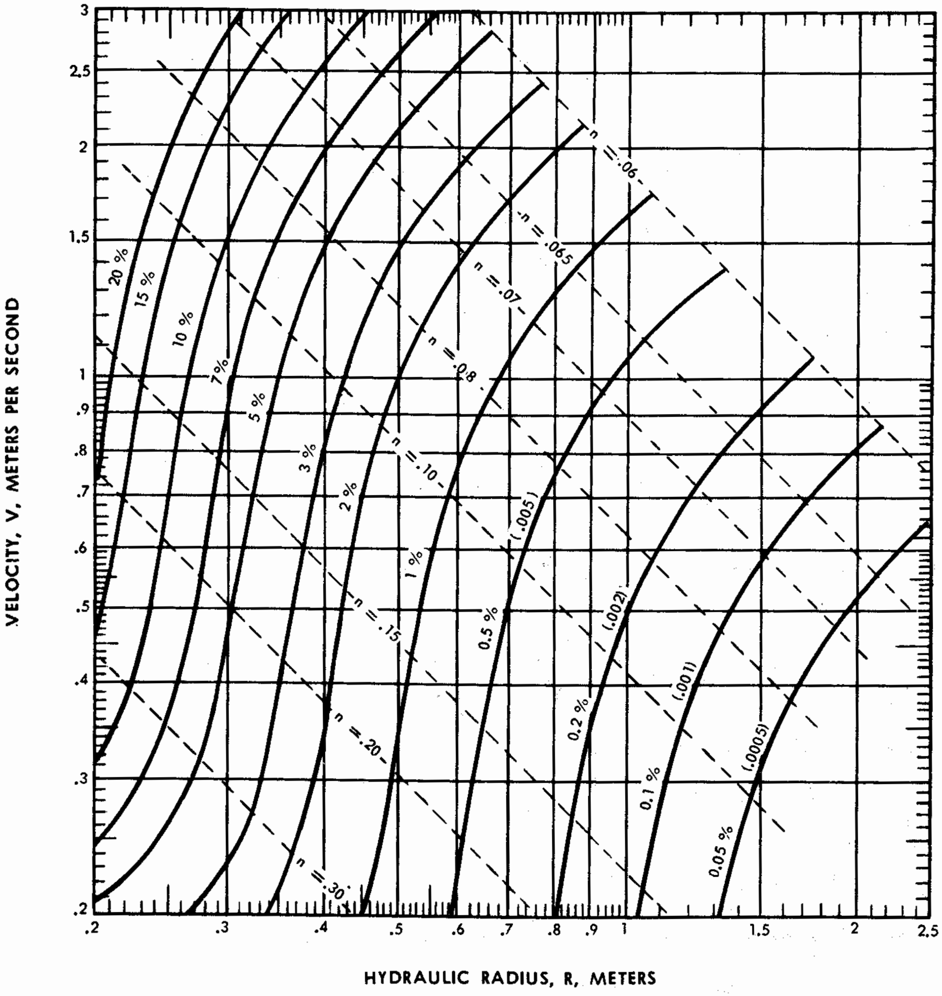


Figure 14. -- Solution of the Manning formula for retardance A (very high vegetal retardance).

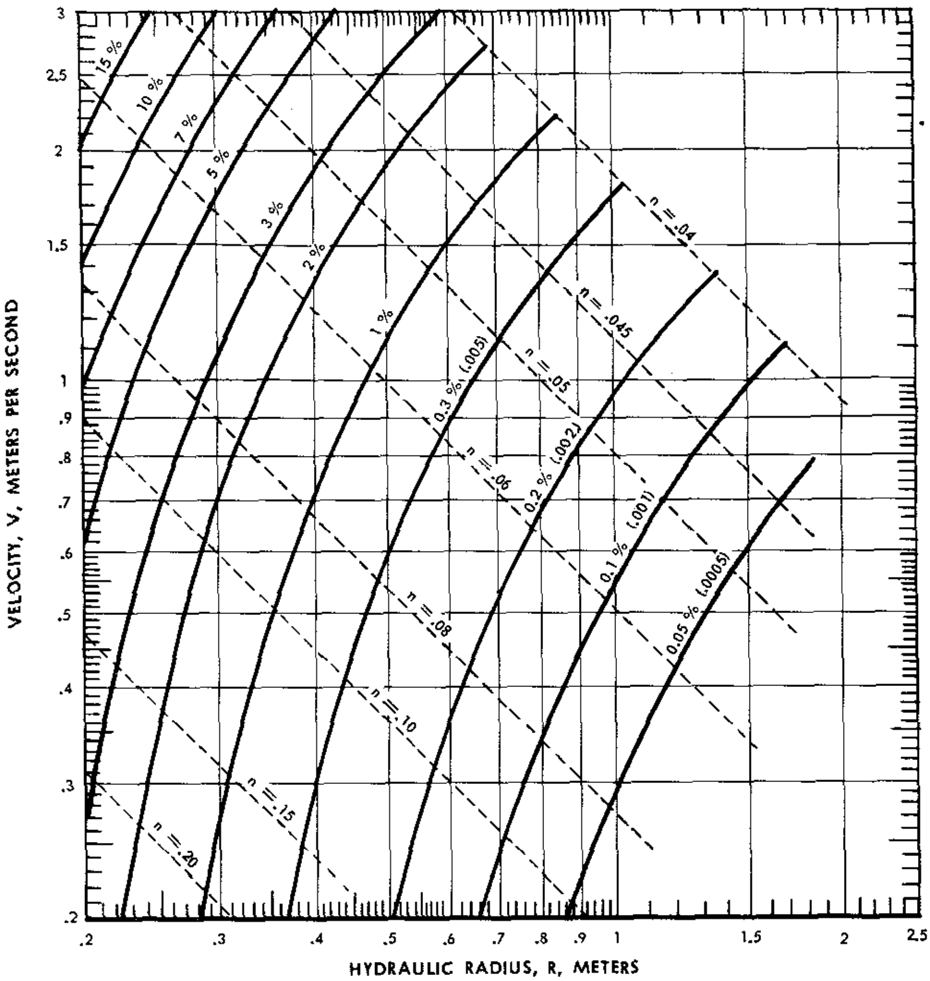


Figure 15. -- Solution of the Manning formula for retardance B (high vegetal retardance).

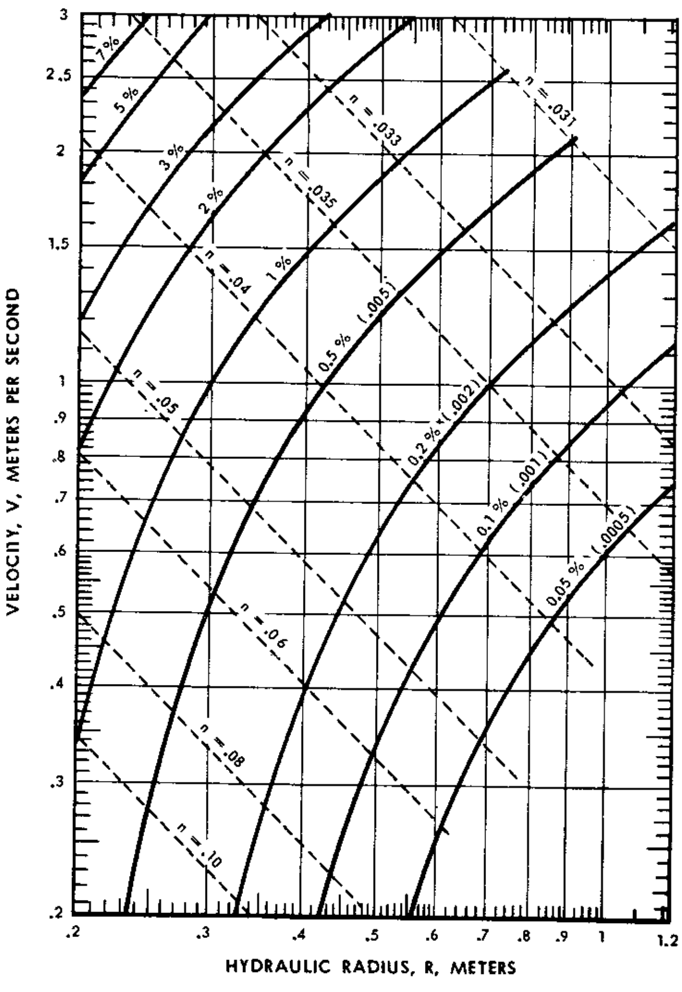


Figure 16. -- Solution of the Manning formula for retardance C (moderate vegetal retardance).

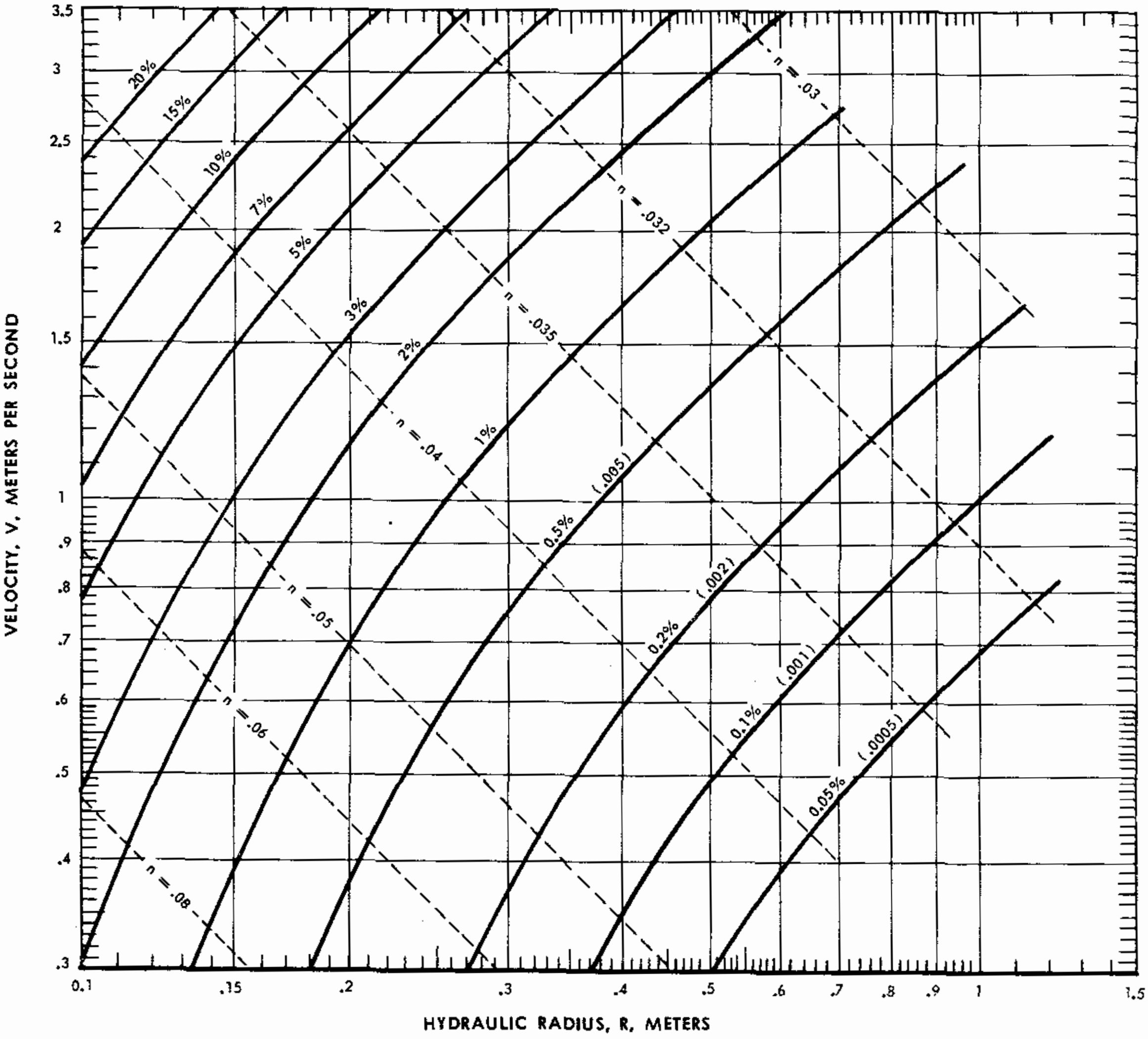


Figure 17. -- Solution of the Manning formula for retardance D (low vegetal retardance).

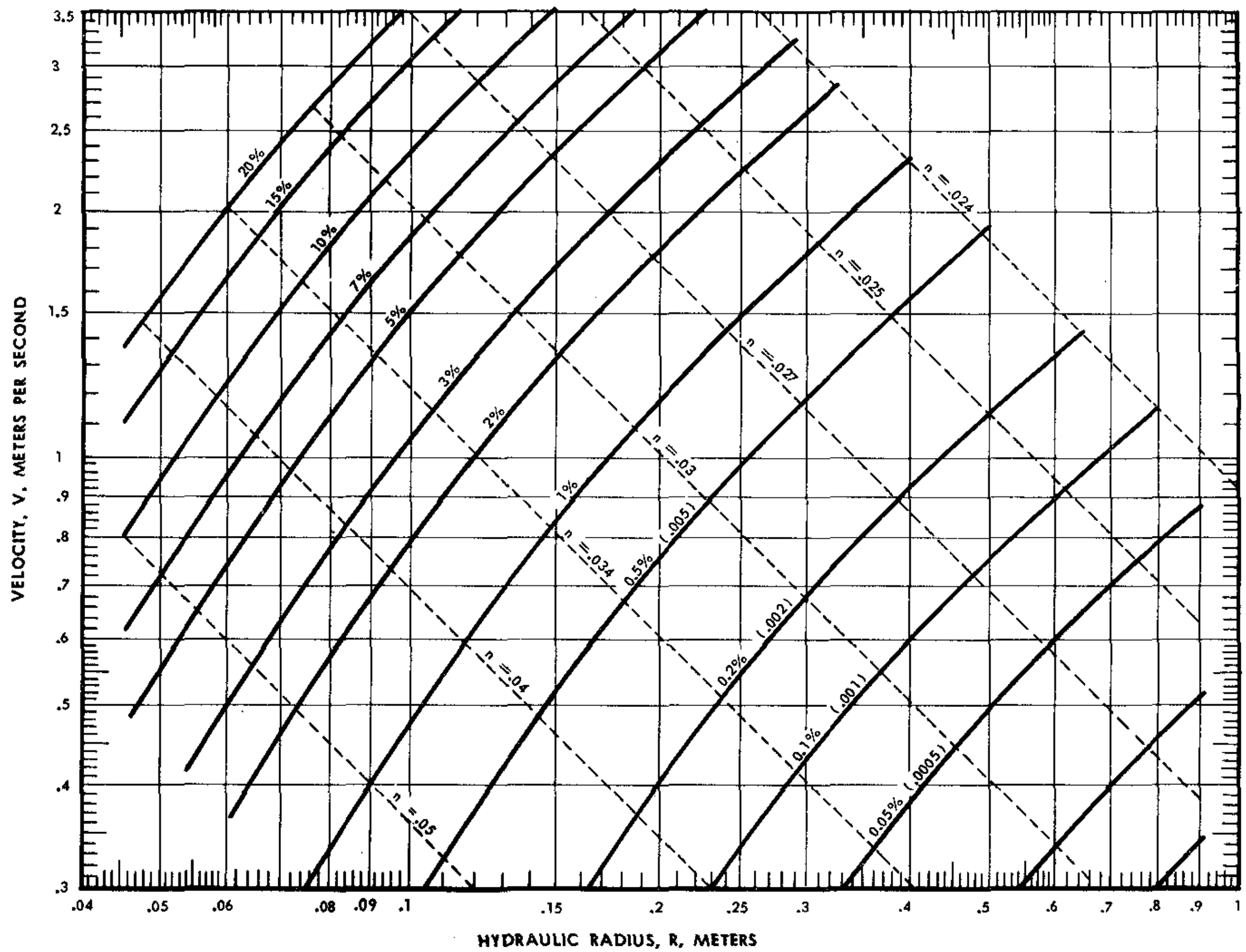


Figure 18. -- Solution of the Manning formula for retardance E (very low vegetal retardance).

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